Beam-Beam Simulation with Electron Lens at RHIC

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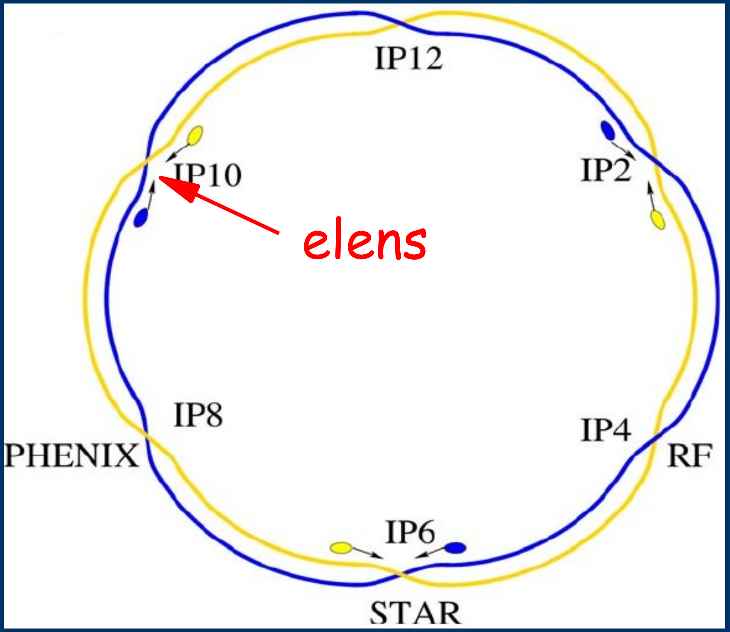
Motivation

- To compensate large tune spread and emittance growth due to head-on interactions in proton-proton run at RHIC, an electron lens with a Gaussian transverse profile was proposed.

- Using a weak-strong code BBSIMC, we investigate effects of electron lens on tune change and beam loss.
  - Figures of merit:
    - tune footprint
    - Dynamic aperture
    - Tune diffusion
    - Particle losses

MODEL: Electron lens simulation at RHIC

- 250 Gev p-p beam
- 2 head-on (IP6 & 8), beta = 0.5m
- Beam intensity: 2E11 per bunch
- Working point: (0.695,0.685)
- 1 e-lens at IP10 , beta = 10m
- NL: sextupoles/IR multipoles



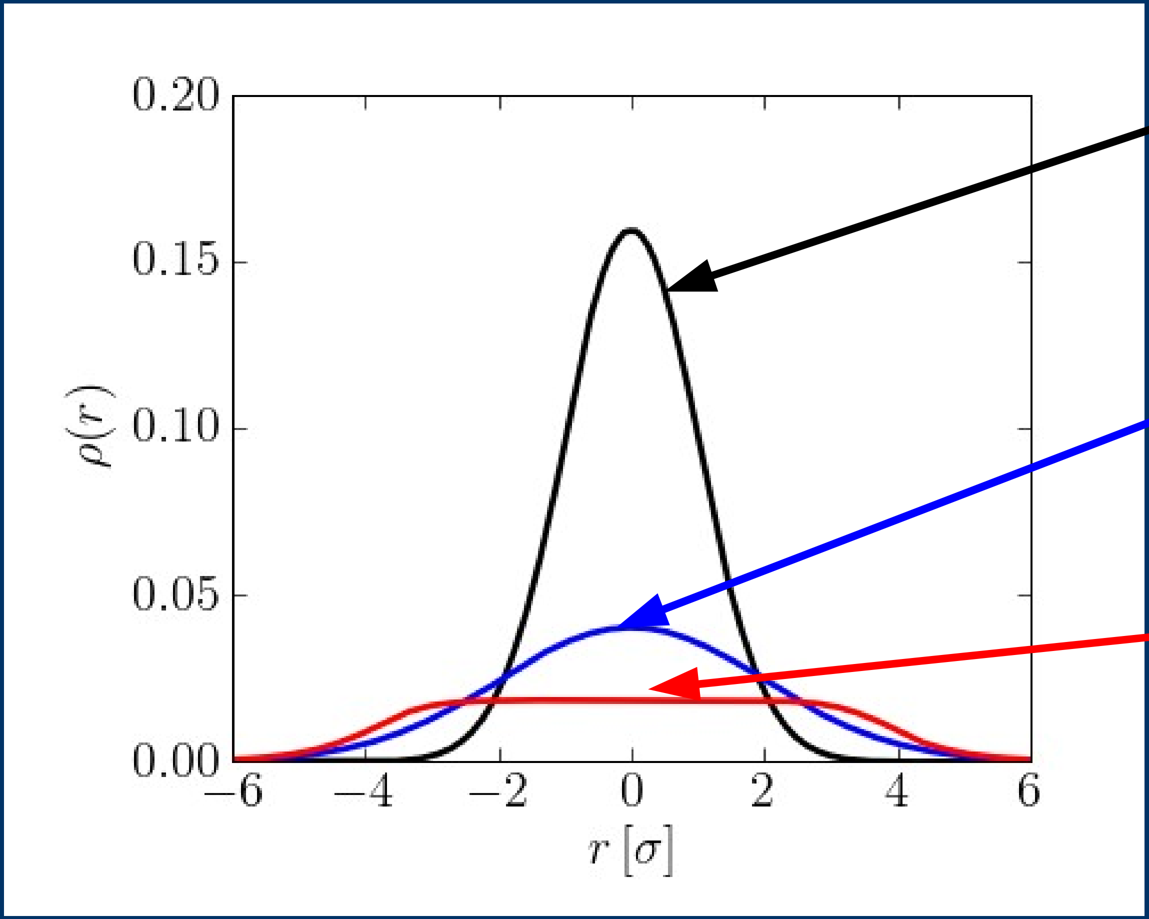
BBSIMC

- 6D weak-strong tacking code
- Linear transfer matrices btwn nonlinear elements
- E-lens is considered as a thin element
  - Gaussian electron beam
  - Smooth Edge Flat Top (SEFT)
- http://www-ap.fnal.gov/~hjkim

Electron Lens Requirement

- **For full tune-spread compression**
  - Electron beam profile should match proton profile at IP (Gaussian)
  - Electron beam intensity should be Ne = N_ip * Np ; N_ip =2, Np=2E11
  - Full tune-spread compression does not help to reduce particle loss (BBSIMC, LIFETRAC, SIXTRACK)
- **For reduction of particle loss**
  - Electron beam profile should match proton profile for tune compression, but other profiles may be more suitable for reducing particle loss.
  - Electron beam intensity may be different from N_ip * Np

Electron beam profiles

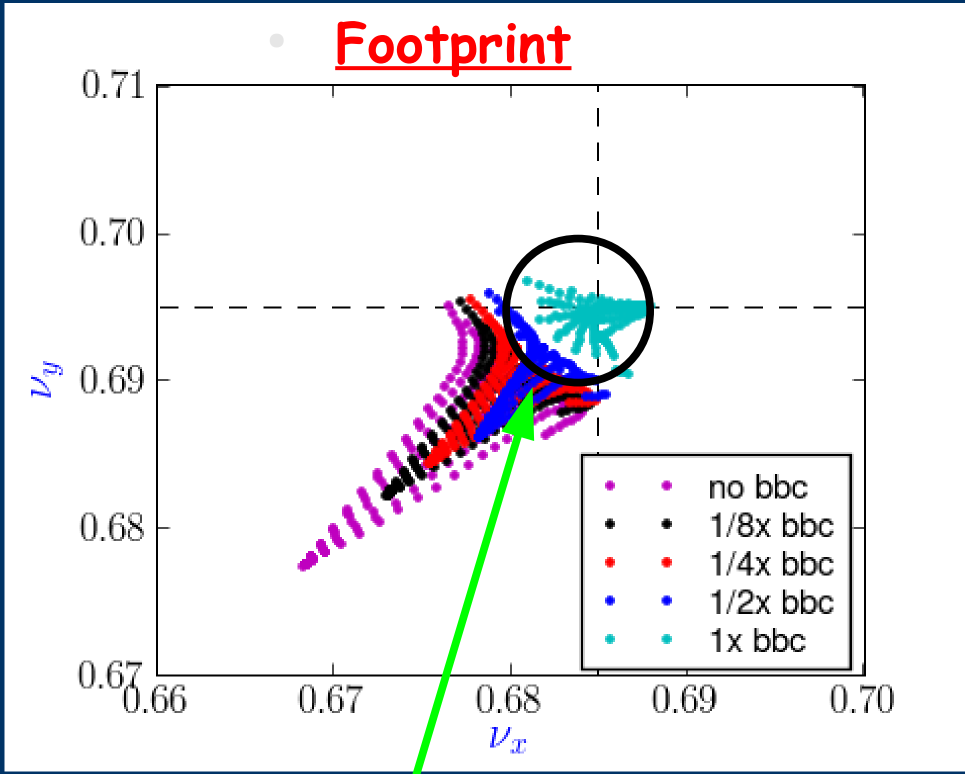


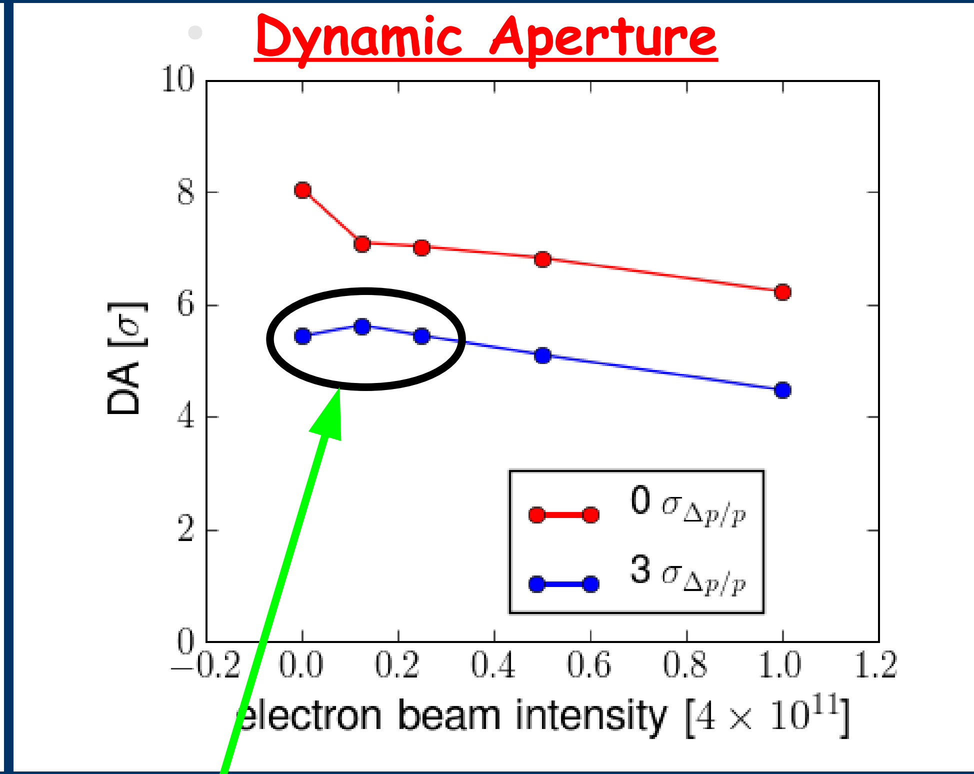
1 sigma Gaussian
- exp(-0.5(r/sigma)**2)
- match to proton beam size

2 sigma Gaussian
- exp(-0.5(r/2sigma)**2)

Smooth Edge Flattop
- 1/(1+(r/4sigma)**8)

Gaussian Electron Lens (1 sigma)



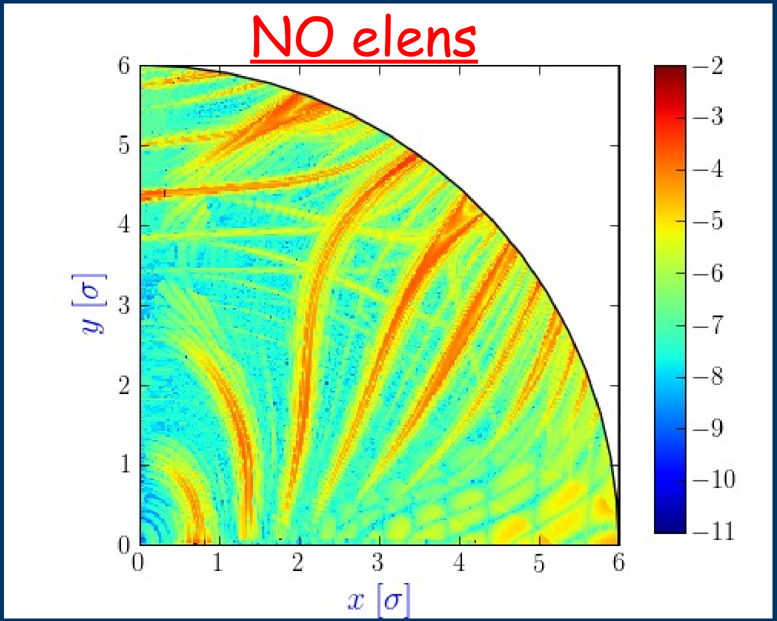


1x bbc fully compensates footprint
Footprint folding is observed.

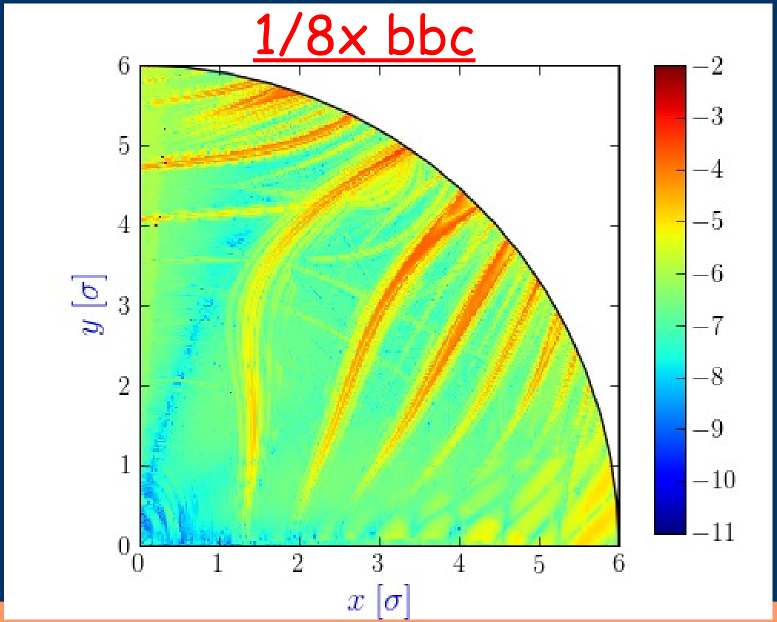
DA is increased at 1/8x bbc

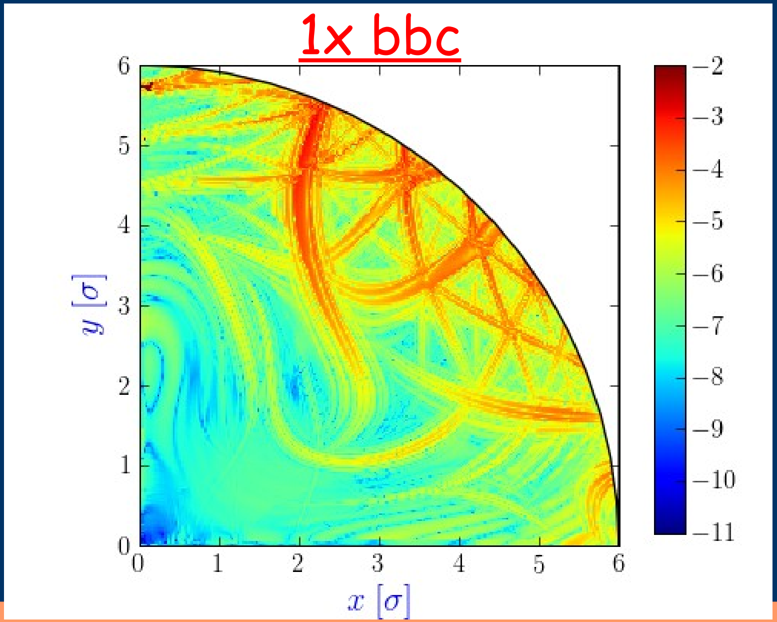
- 1x bbc = beam-beam compensation with Ne = Nip * Np = 2*2E11

Gaussian Electron Lens (1 sigma)



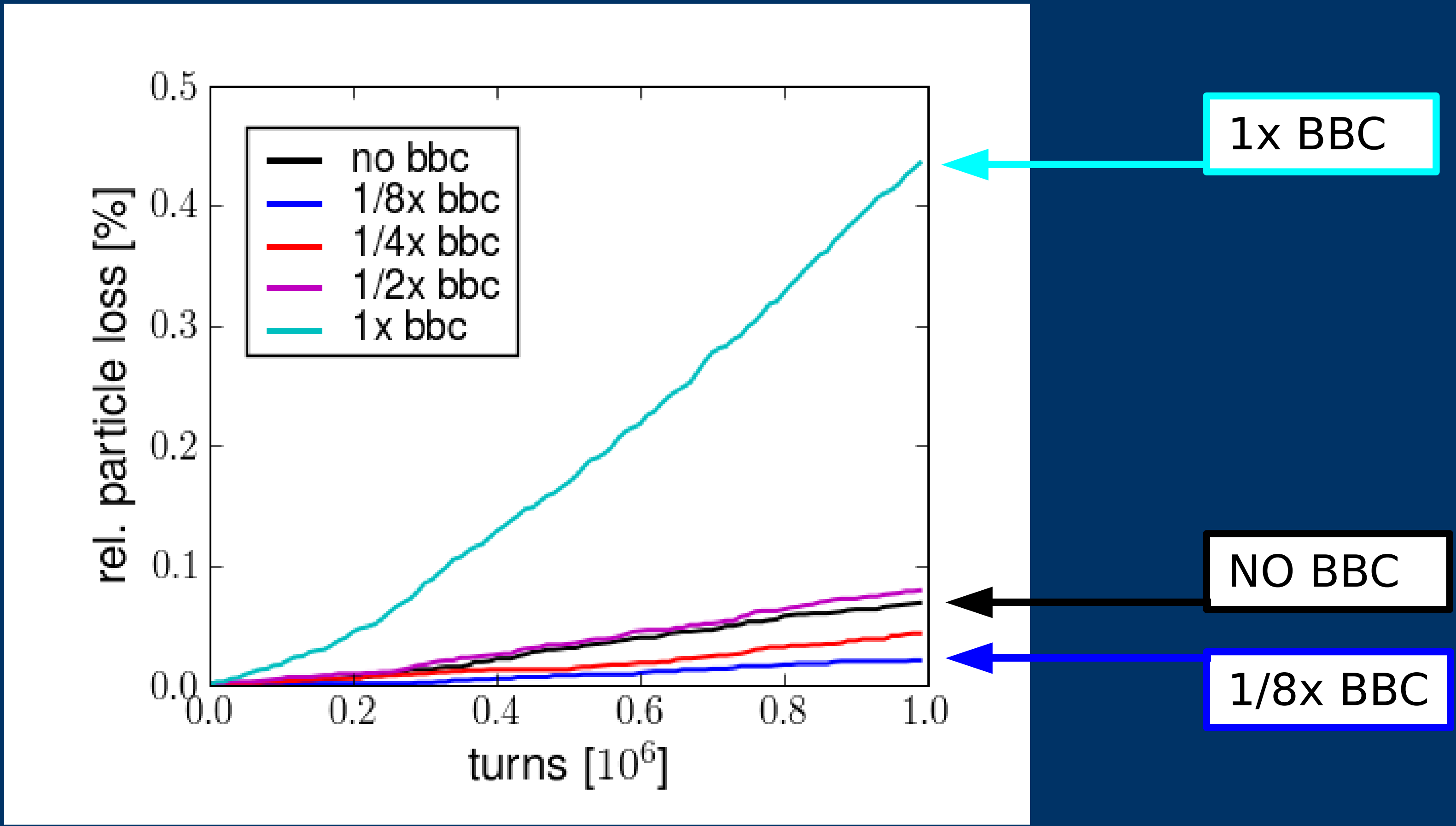
- Tune Diffusion: tune change btwn first and second 1024 turns
  - DQ = sqrt(dQx^2 + dQy^2)
- 1x bbc: decrease tune change at small amp. but increase at large amp.
- 1/8x bbc: decrease tune change at both small and large amp.





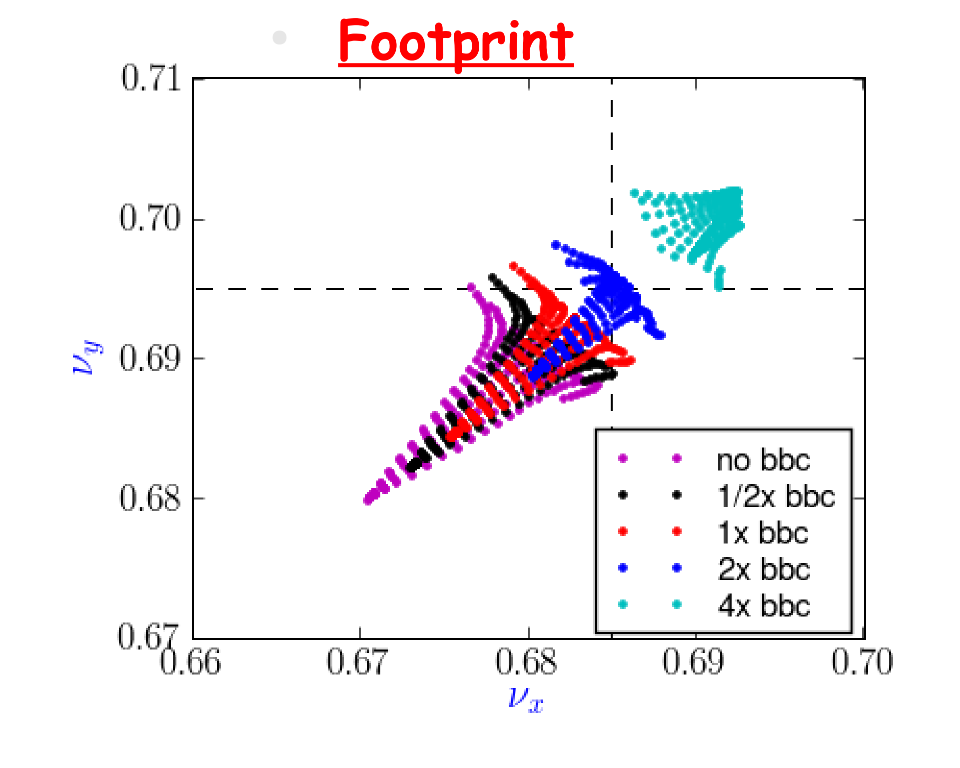
Gaussian Electron Lens (1 sigma)

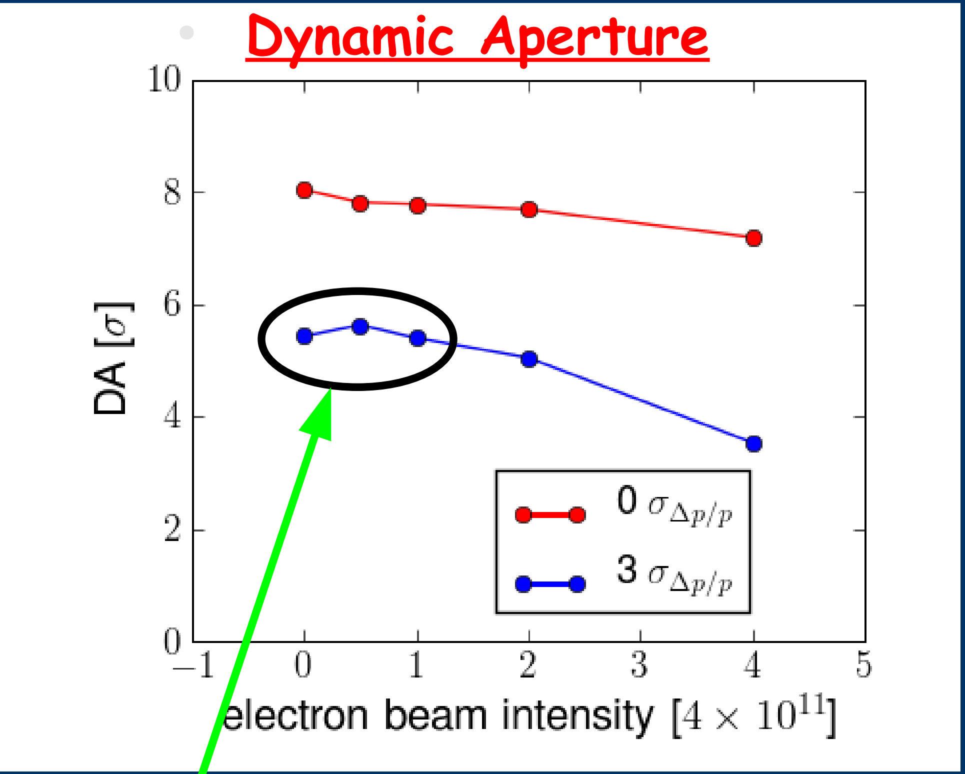
- Particle loss



- Small Ne reduces beam loss: Ne < 0.5 Nip * Np
  - (loss with 1x bbc)/(loss with NO bbc) ~ 600%
  - (loss with 1/8x bbc)/(loss with NO bbc) ~ 30%

Gaussian Electron Lens (2 sigma)

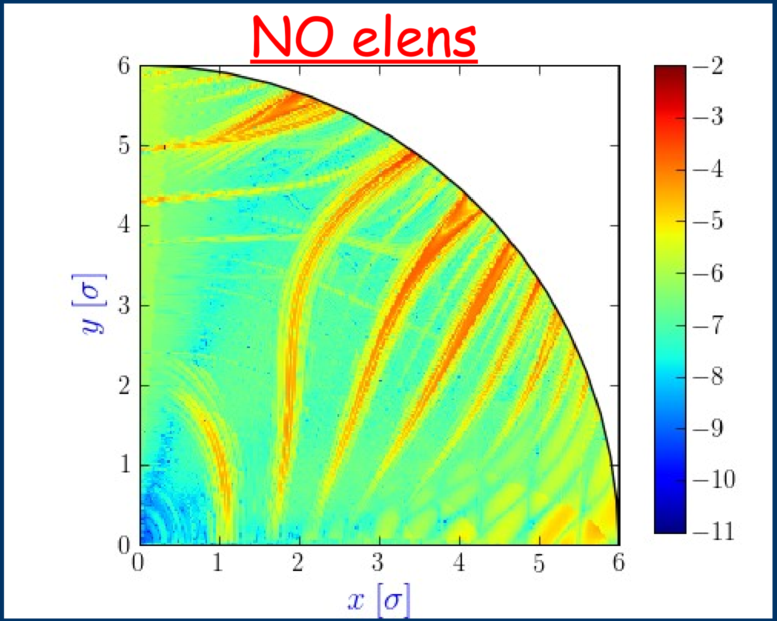




DA is increased at 1/2x bbc

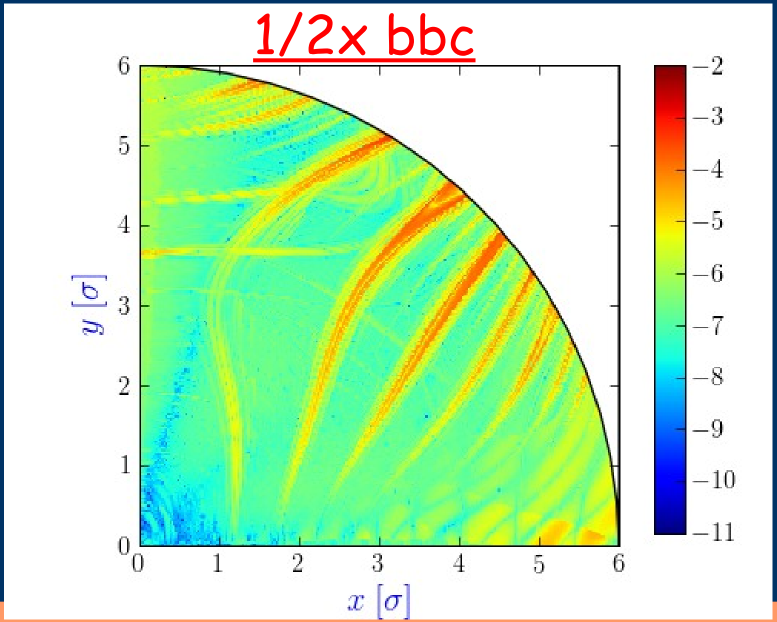
- Peak of 4x bbc electron beam profile is matched to that of 1x bbc at 1 sigma Gaussian.

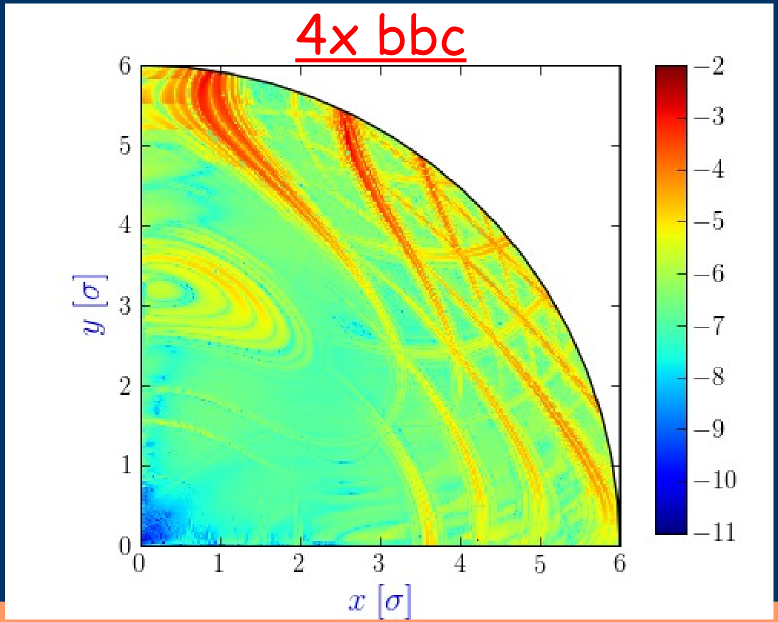
Gaussian Electron Lens (2 sigma)



- Tune Diffusion

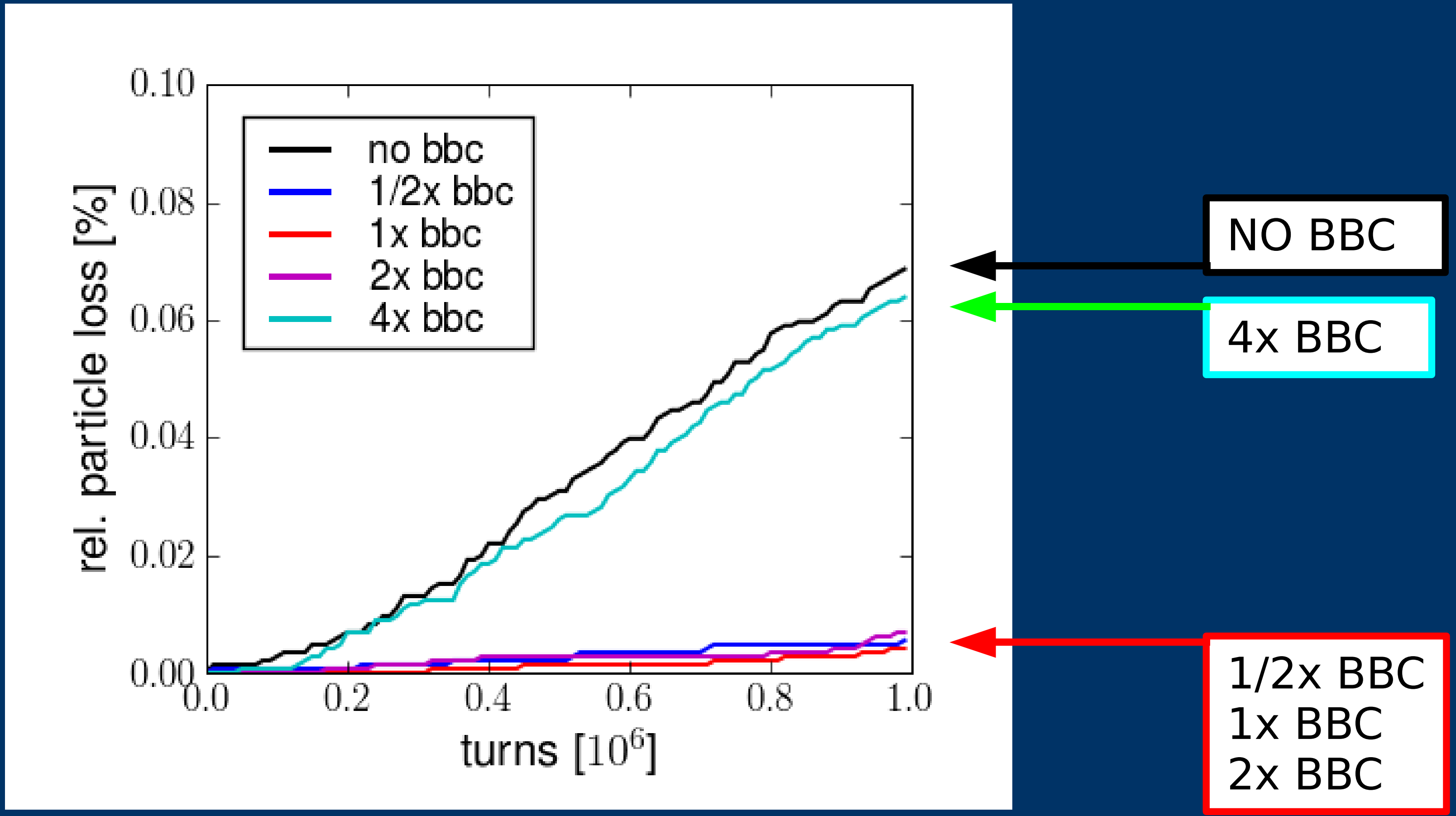
- 4x bbc: decrease tune change at small amp. but increase at large amp.
- 1/2x bbc: decrease tune change at both small and large amp.





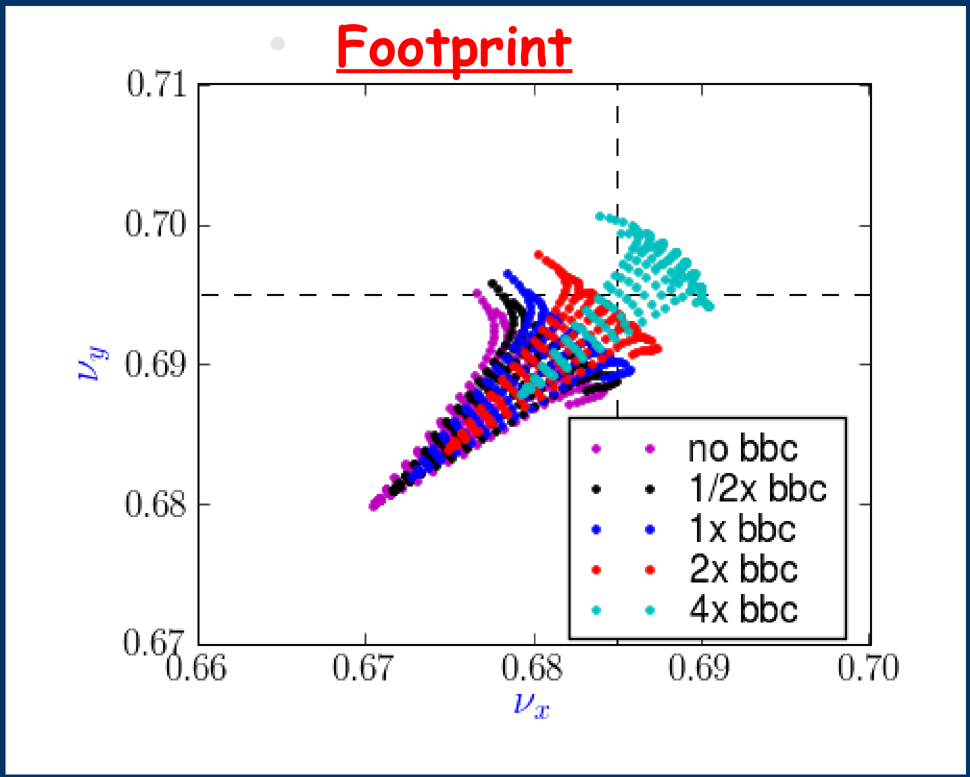
Gaussian Electron Lens (2 sigma)

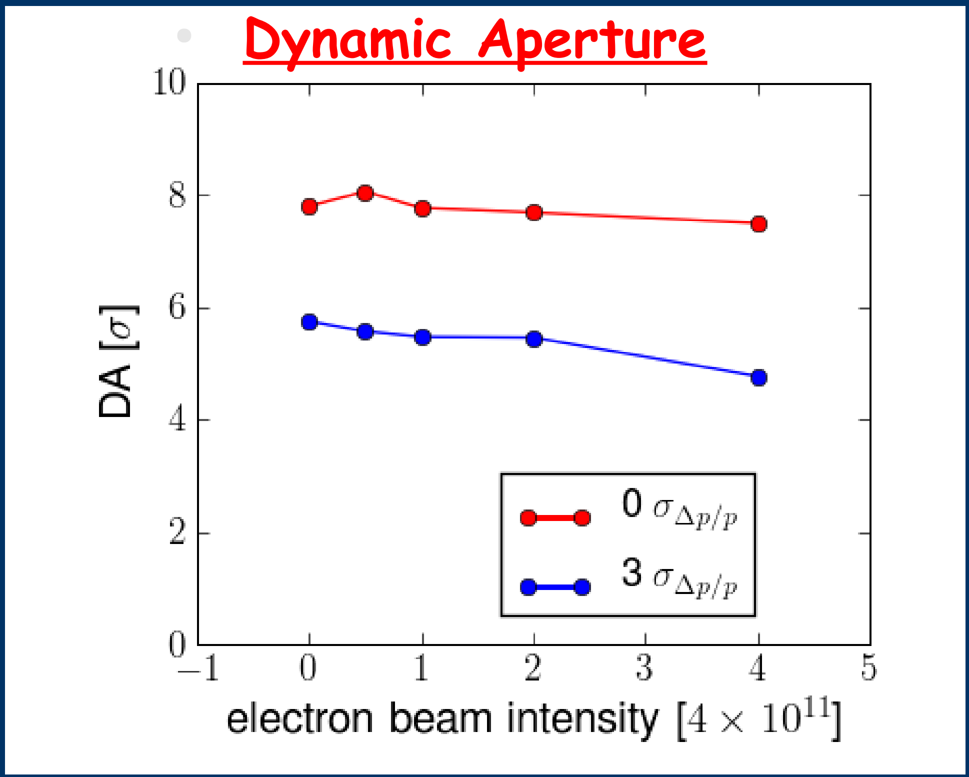
- Particle loss



- Small Ne reduces beam loss:
  - (loss with 1/2x bbc)/(loss with NO bbc) ~ 10%

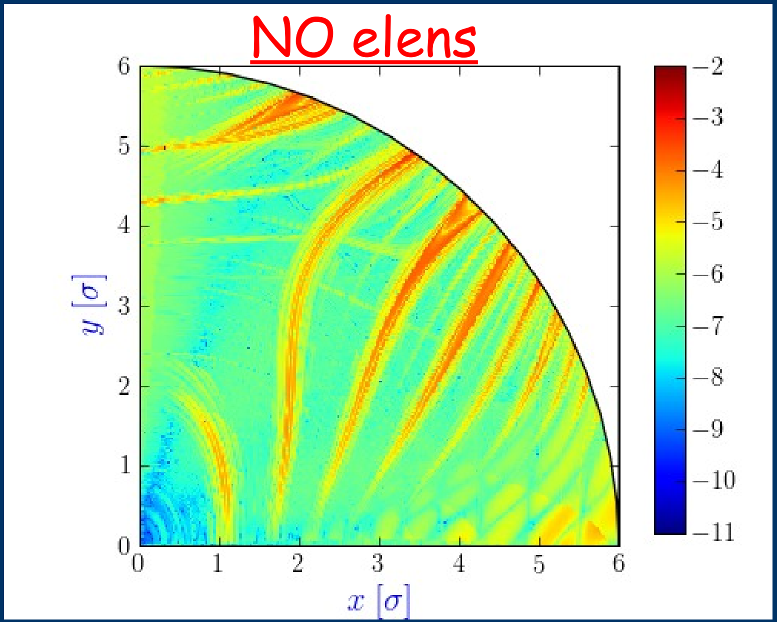
SEFT Electron Lens (4 sigma)





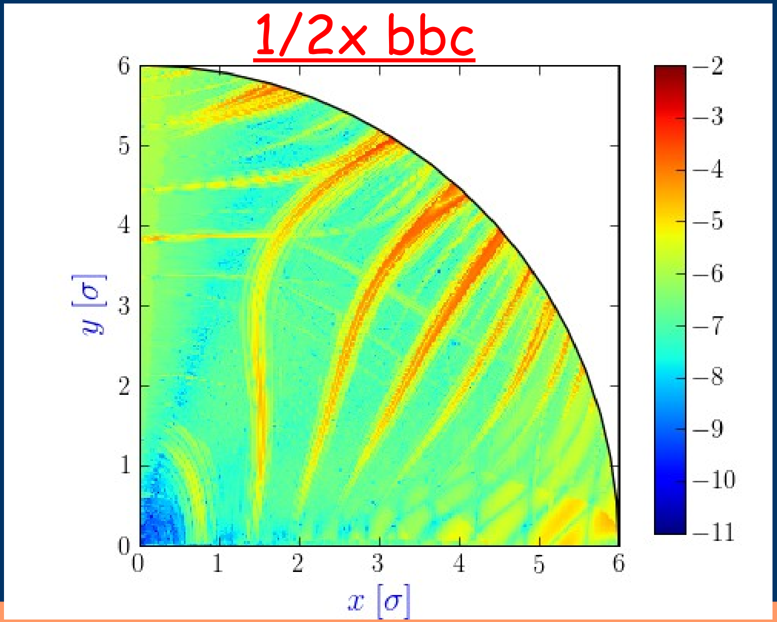
- Shape of footprint with compensation is almost the same as without compensation.
- Dynamic aperture is almost the same up to 2x bbc.

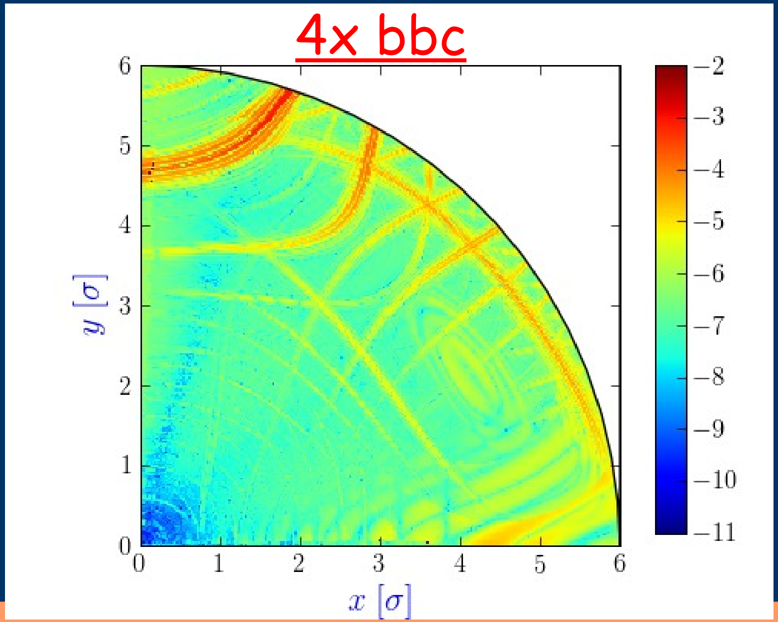
SEFT Electron Lens (4 sigma)



- Tune Diffusion

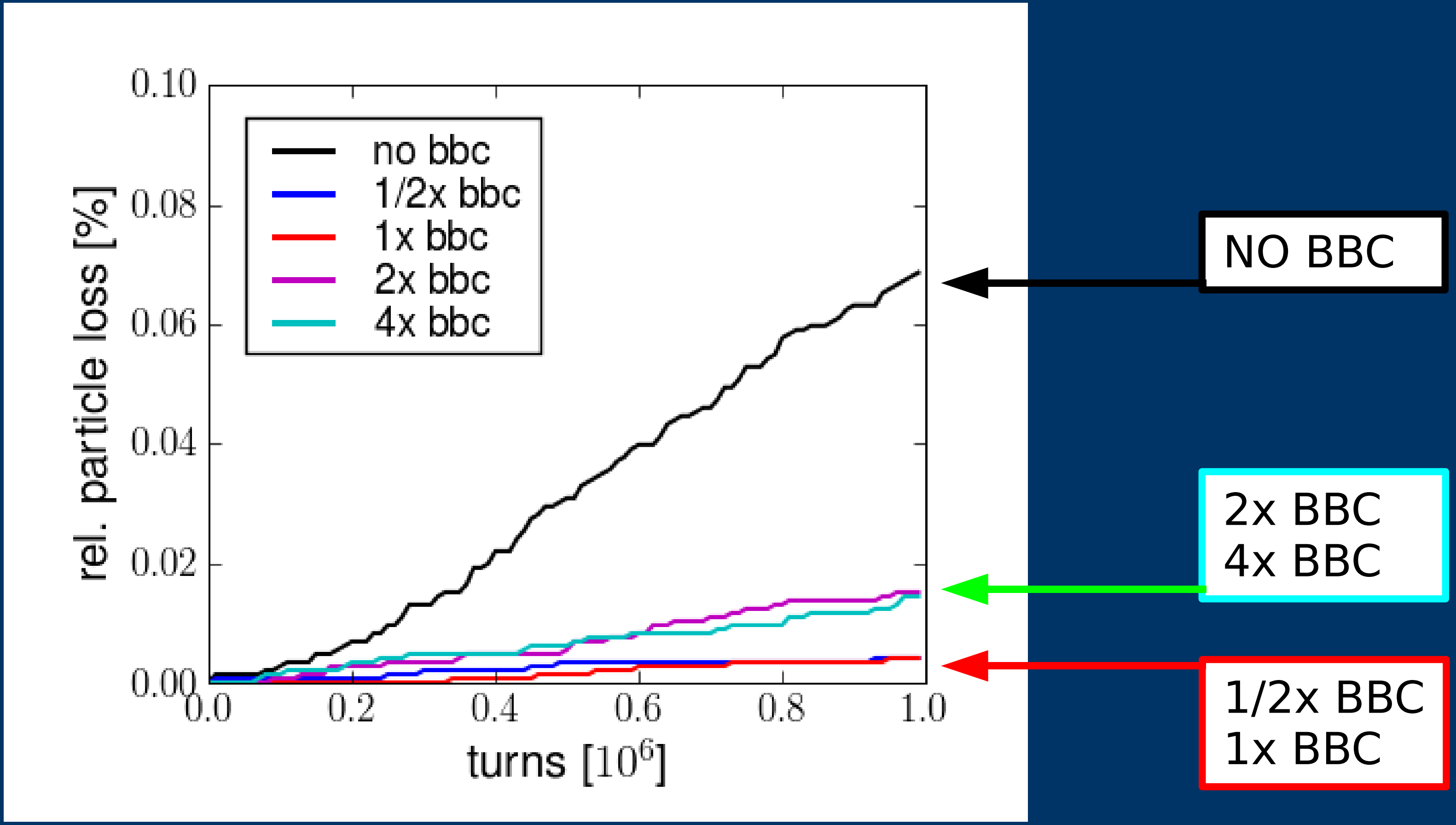
- 4x bbc: decrease tune change at small amp. but increase at large amp.
- 1/2x bbc: decrease tune change at both small and large amp.





SEFT Electron Lens (4 sigma)

- Particle loss



- Small Ne reduces beam loss:
  - (loss of 1/2x bbc)/(loss of NO bbc) ~ 10%

Comparison of electron beam distributions

Profile	Intensity (N_ip*Np)	Dynamic aperture (sigma)	Particle loss (Relative to NO elens)
1 sigma Gaussian	1/2	5.10	115%
	1/4	5.44	63%
	1/8	**5.63**	**30%**
2 sigma Gaussian	2	5.05	10%
	1	5.40	8%
	1/2	**5.63**	**6%**
SEFT	2	4.77	22%
	1	5.47	6%
	1/2	**5.57**	**6%**

- Particle loss is relatively insensitive to electron lens current variations below threshold current with 2 sigma Gaussian and SEFT profiles.

Summary

- Full tune-spread compression also causes footprint folding and increases particle loss. Partial tune-spread compression without inducing footprint folding may reduce particle loss.

- Tune diffusion is closely related to particle loss.

- There is a threshold electron beam intensity below which beam life time is increased

Profile	Threshold (N_ip*Np)
1 sigma G	0.5
2 sigma G	2
SEFT	4

- Particle losses for 2 sigma Gaussian and SEFT profiles are relatively insensitive to intensities below threshold.

- Wider electron beam profile than proton at elens location is found to increase beam life time. Validation with better statistics in progress.